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IONOSPHERIC CONVECTION AND STRUCTURE USING GROUND-BASED DIGITAL IONOSONDES

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Ground-based digital ionosonde observations of the winter polar cap F-region have been used to demonstrate that the magnetospherically induced ionospheric convection can be measured for the bottomside ionosphere. A number of 24-hour measurements made at Thule, Greenland indicate that the drift direction is predominately anti-sunward with speeds that vary between 300 and 900 meters/second. Similar measurements made at Goose Bay, Labrador show a steady westward drift until local magnetic midnight and

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20. ABSTRACT (Continued)

then a change to an eastward drift. The ionospheric drifts observed at Goose Bay are consistent with the expected sunward return flows of the two-cell polar plasma convection pattern.

The utility of data from a network of digital ionosondes is enhanced through automatic scaling of parameters needed for research and radio wave propagation management. The values of hmF2 deduced by real-height analysis of automatically scaled Digisonde ionograms have been compared with simple methods based on routinely scaled ionospheric characteristics. Systematic discrepancies were found between the hmF2 values obtained from the simple methods and the real-height analysis. Overestimates of 15-20 km were found for the night data from five stations and low solar activity. Daytime discrepancies are normally less, with 80% showing agreement within ±10 km. Analyses, similar to those presented here, are useful for defining the limits of the simple methods and for gaining confidence in the automatically obtained data from the expanding, world-wide network of digital ionosondes.

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FOREWORD

Within several years, a world-wide network of approximately 40 digital ionosondes will be operating to further understanding of solar-terrestrial and radio physics. The digital ionosondes possess capabilities to provide data bases that heretofore were limited to instruments requiring a significant capital investment (e.g. incoherent scatter radar) or were labor intensive to obtain (e.g. real-height analyses).

With the maturation of the Digisonde hardware, there has been associated analytical work to develop automatic, computer-based algorithms that will provide reliable data bases of the aforementioned types.

The University of Lowell Center for Atmospheric Research, with cooperation and support from the Air Force Geophysics Laboratory, recently contributed two journal papers that document the approaches and some results of the associated analytical work. The first paper summarizes the technique and initial results of using the Digisonde to obtain ionospheric drifts. Results are presented from experiments conducted at Thule, Greenland and at Goose Bay, Labrador. These results demonstrate that a systematic study of ionospheric drifts is now feasible with a network of ground-based digital ionosondes. The second paper compares F layer peak heights obtained from true height analyses of automatically scaled ionospheric parameters to those derived from the routinely scaled ionospheric characteristics. Continued assessment of the computer-based analytical methods identify limits and provide confidence in the data bases that result from the expanding, world-wide network of digital ionosondes.

This scientific report includes the recent journal articles mentioned above:

Reinisch, B. W., J. Buchau and E. J. Weber, "Digital Ionosonde Observations of the Polar Cap F REgion Convection," Physica Scripta, Vol. 36, pp. 372-377, 1987.

McNamara, L. F., B. W. Reinisch and J. S. Tang, "Values of hmF2 Deduced from Automatically Scaled Ionograms," Adv. Space Res., Vol. 7, No. 6, pp. (6)53-(6)56, 1987.

Physica Scripta. Vol. 36, 372–377, 1987.

Digital Ionosonde Observations of the Polar Cap F Region Convection*

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Abstract

Ground-based drift observations of the winter polar cap F-region show that the magnetospherically induced ionospheric convection can be measured for the bottomside ionosphere. A digital ionosonde with four spaced receiving antennas operated at Thule, Greenland (86° CGL) in the Doppler-drift mode. A number of 24-hour measurements indicate that the drift direction changes linearly as a function of time in accordance with the predicted antisunward convection pattern. The drift velocities vary from 300 to 900 m/s.

Measurements at a subauroral station (Goose Bay, Labrador, 65° CGL) with the same spaced-antennas-Doppler-drift technique show a steady westward drift until local magnetic midnight and a fast switch-over at that time to an eastward drift. We conclude that the observed subauroral drifts are the sunward return flows of the polar plasma convection, and the switch-over occurs when the station rotates from the dusk cell into the dawn cell.

1. Introduction

Satellite observations have established the existence of a two cell convection pattern in the polar F region drift when the interplanetary magnetic field (IMF) has a southward component [1, 2]. This convection pattern produces an antisunward drift at the highest latitudes and sunward drift at lower latitutdes in the auroral zones. The plasma flow pattern is less predictable and more irregular when the IMF has a northward component [3, 4]. Wygant *et al.* [5] have shown that the response time of the convection to changes in the IMF is two hours or more.

The University of Lowell and the Air Force Geophysics Laboratory have developed ground-based observation techniques that can monitor the plasma convection as a function of time. We have begun to measure the F-region drift at three high latitude stations: (1) Thule, Greenland, 86° CGL, (2) Goose Bay, Labrador, 65° CGL, and (3) Argentia, Newfoundland, 58° CGL. In this paper we give a brief description of the high-frequency (HF) radio technique used to measure the ionospheric drift and present some of the results of the Thule and Goose Bay observations.

2. Spaced-antenna doppler drift technique

Spaced-antenna HF observations of ionospheric drifts is an effective method to study the dynamics of the ionized atmosphere. Vertically transmitted HF waves illuminate a large area of several hundred kilometers diameter in the F region; an array of antennas receives the signals reflected from the ionosphere. For the measurements described in this paper we used Digisondes [6, 7], i.e., advanced digital ionosondes, that operated alternatively in the ionogram and the drift modes. Actually, the ionograms were spaced by five minutes and the time in between was filled with a number of 16 sec drift measurements. The individual antennas of the receiving array are multiplexed at the pulse repetition rate (200 Hz). The time series received at each of the antennas is Fourier transformed in real time resulting in four complex spectra (in the case of four receiving antennas) at the end of each measurement period. The spectral resolution was 0.125 Hz.

Cross-correlation [8] of the complex spectra from the spaced antennas determines the angle of arrival for each spectral component containing significant signal energy. As a result of this analysis one can construct a sky map showing the location of each reflection point, or source [9], specified by a given Doppler frequency, which defines the radial velocity component of the moving plasma for this source. The Doppler frequency d is given by

$$d_s = \frac{1}{\pi} v \cdot k_s \quad S = 1, 2, \ldots \text{ (source index)}$$

where v is the drift velocity and k the wave vector. An example of such a sky map is shown in Fig. 1. The majority of the sources are located in the south-east with a zenith angle of about 20°. The Doppler frequencies vary from + 1.06 Hz (labeled 1) to − 0.81 Hz (labeled 7). By assuming that the observed Doppler shifts are the result of a uniform bulk motion of the reflecting plasma, one can determine the three-dimensional velocity vector v which, in the least-squares-error sense, best represents the Doppler frequencies d_s measured at the source locations specified by k_s.

It is important to realize that the 14 sources shown in the sky map of Fig. 1 existed simultaneously within a 16 s time window. The existence of the many sources was first established by the spectral analysis, and then their location was found by cross-correlating the antenna signals in the spectral domain. The dimensions of the receiving antenna array are shown in Fig. 2 together with the array pattern for a 10 MHz signal. It is evident that the angular resolution of the array would have been much too low to resolve the different sources shown in Fig. 1, if it had not been for the preselection by the Fourier analysis.

* This paper was contributed to the "SCOSTEP Sixth Quadrennial International Solar-Terrestrial Physics Symposium", Toulouse, 1986, and will be included in part II of the Conference proceedings (Editors B. Hultqvist, D. Rees and U. von Zahn)

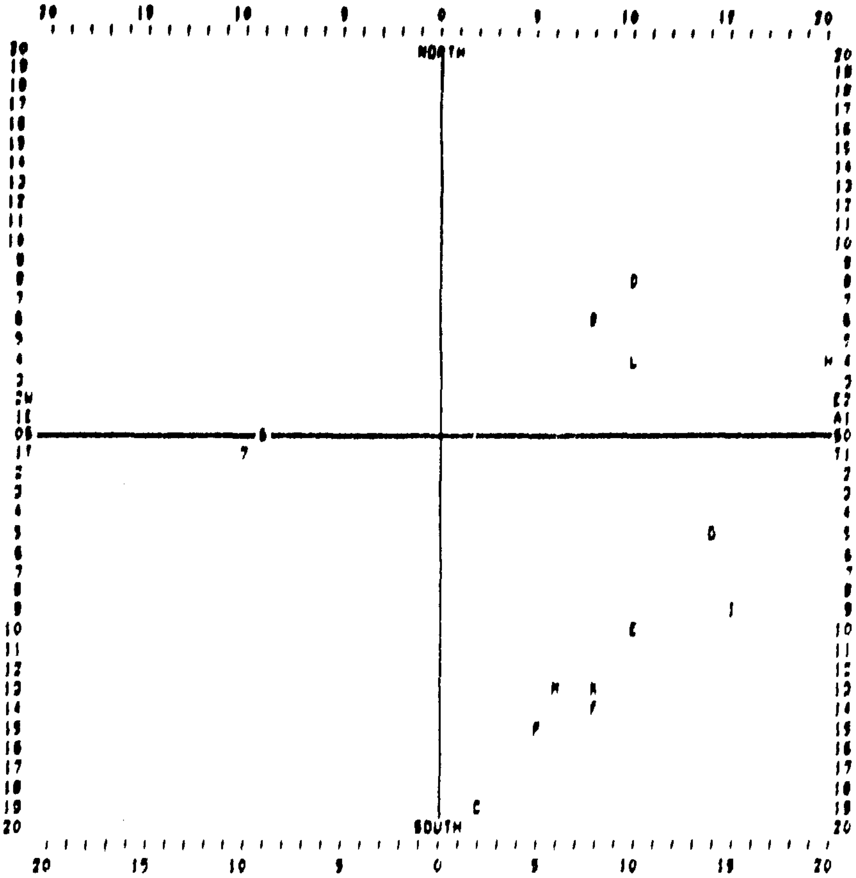

Fig. 1. Doppler Skympa Thule 17 Mar 85 0440 UT Mpa shows the locations and Doppler frequencies of echo sources measured during an 16 second observation period. The map resolution is 7.9 km for a range of 315 km (45° zenith angle at the corners), and the Doppler resolution is (1/8) Hz (1 = −1/16 Hz, 2 = −3/16 Hz, . . . , A = +1/16 Hz, B = +3/16 Hz, . . .). Only sources with amplitudes within 6 dB of the peak amplitude are shown.

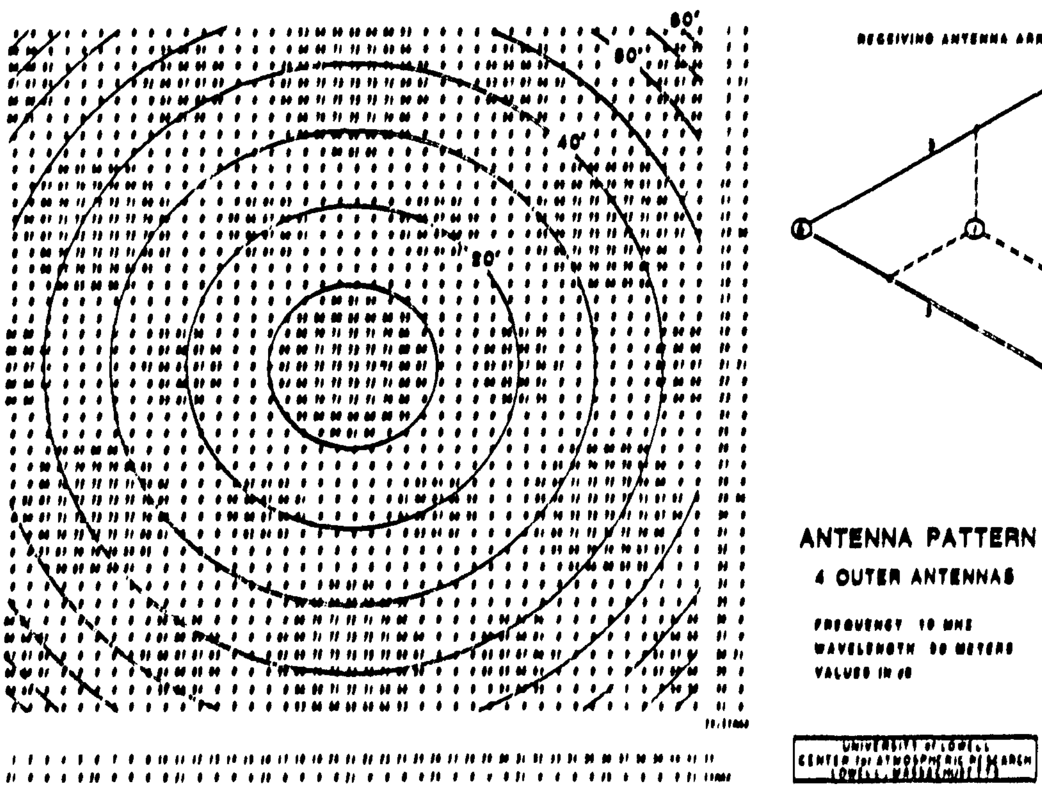

Fig. 2. Antenna Pattern. The receiving antenna array is arranged in an equilateral triangle with 100 m side length and one antenna in the center. Each cross-loop antenna received left-hand circular polarization. The main lobe of the array is about 6° wide for a 10 MHz signal. The major sidelobes (with same gain as the main lobe) occurs at 40°.

3. Drift observations at Goose Bay

In an effort to study the diurnal variation of the F region drift we calculated the average drift velocity for every 15 min interval. The direction (azimuth) and the magnitude of the horizontal drift component are plotted as function of time in Figs. 3 and 4 for two winter days at Goose Bay. In both cases, the drift is westward before local midnight and changes within about one hour to a pre-dominantly eastward drift. This behavior is exactly what is expected in the presence of the two-cell polar convection pattern. Goose Bay at 65° CGL is under the sunward return flow (magnetic west) of the dusk cell before local midnight. At midnight, Goose Bay rotates through the Harang discontinuity to the dawn cell where the sounder now senses the sunward flow (magnetic east) of the dawn cell.

The typical velocity values are around 100 m/s, but at times the velocity reaches values of 300 m/s or slightly above (not shown in the figures). The vertical velocity components are indicated in the speed panels by + (upward) or − (downward) signs, in general they remain below 50 m/s.

The examples shown here were selected to demonstrate the midnight velocity reversal. There are many other days where the reversal occurs but is not as clearly defined. In cases where the velocities are very small our method produced unreliable results. What needs to be done in such situations is to increase the Doppler resolution by increasing the observation period (integration time) from 16 s to 32 s or more, in order to separate the different reflection points.

At times the drift direction changes unexpectedly, as at 07 AST on 21 January 1982 (Fig. 3); for about three hours the drift direction is westward instead of eastward as expected in the morning hours. Such irregular changes could be the result

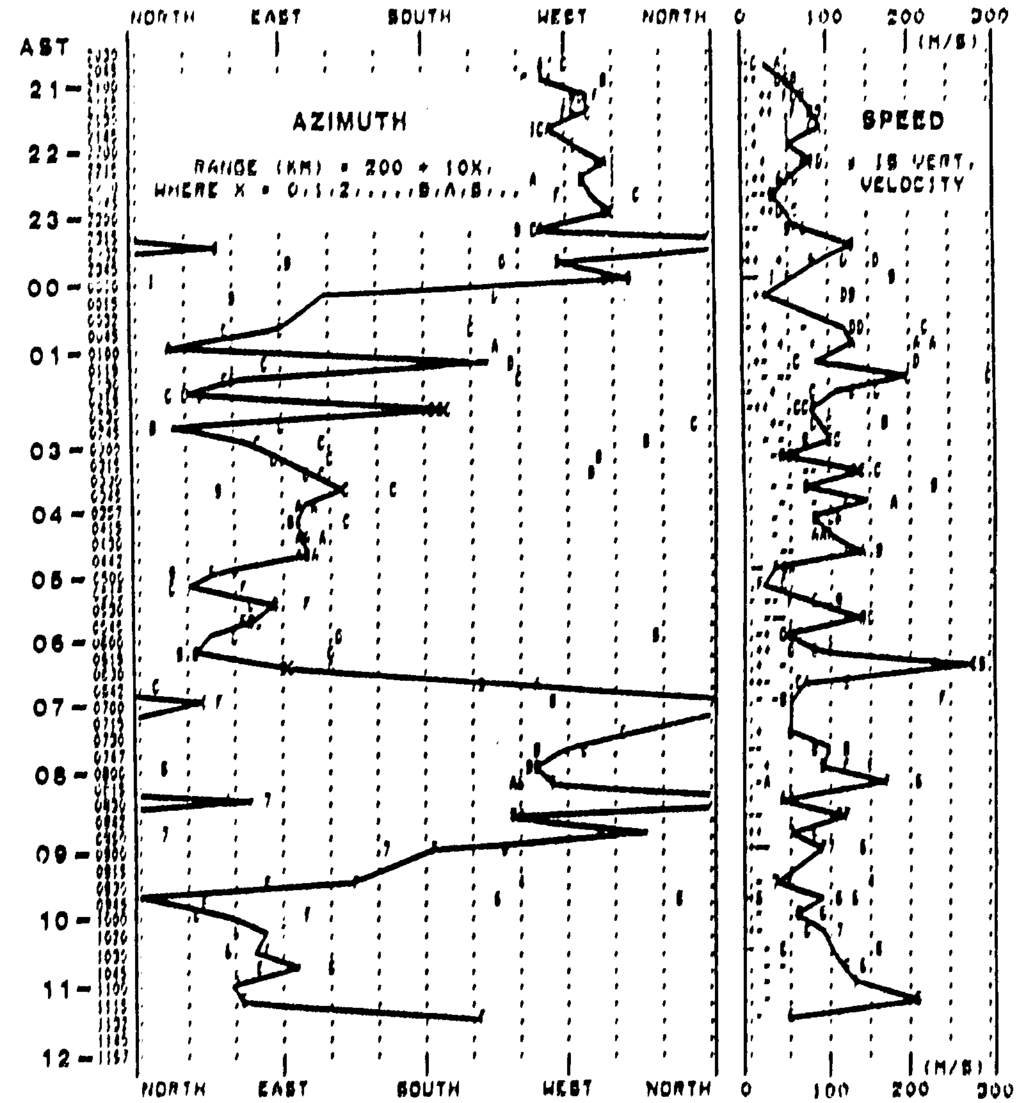

Fig. 3. F-Region Drift at Goose Bay, Labrador, 20/21 Jan 82, at 20 to 12 AST. The direction (azimuth) and the magnitude (speed) of the horizontal component of the drift are shown as function of time. The vertical velocities are marked as + (upward) and − (downward) on the right panel. Simultaneous observation at three sounding frequencies gives drift at different heights (200 km to 360 km). Solid curve connects median values.

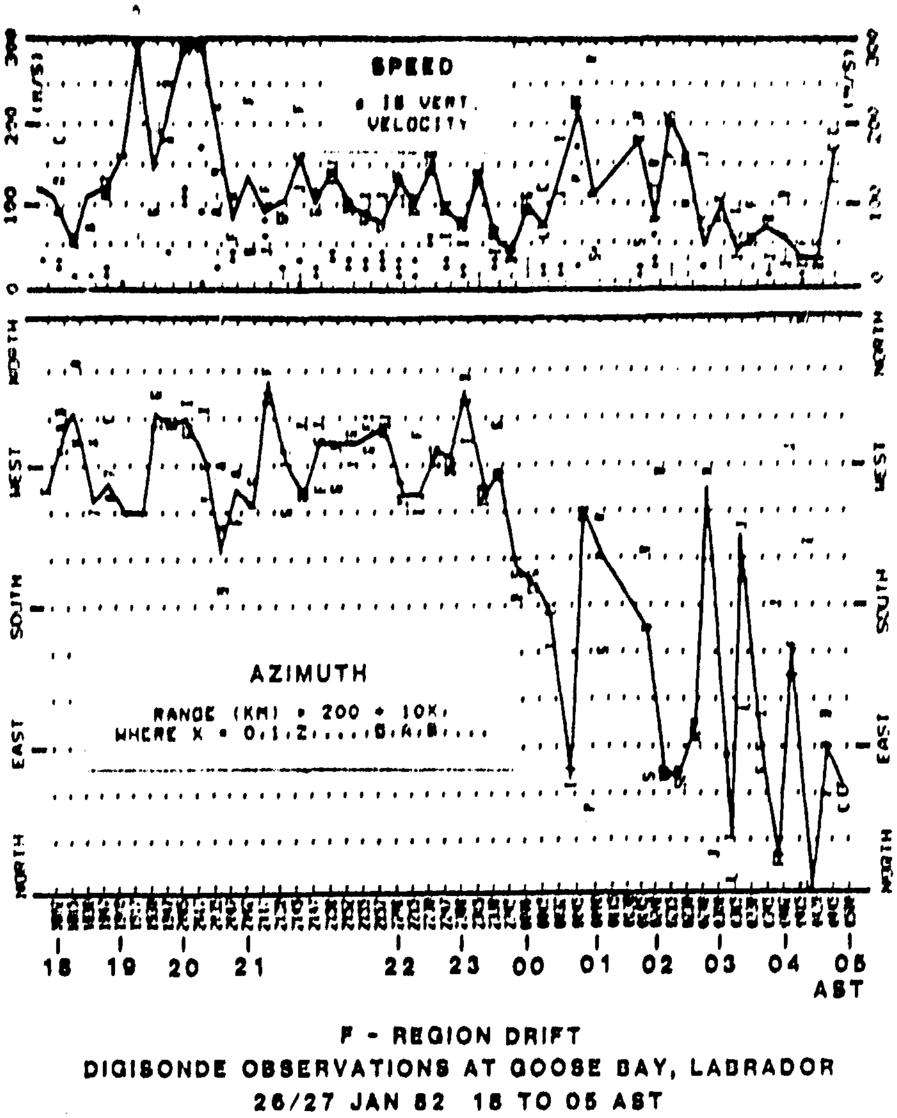

Fig. 4. F-Region Drift at Goose Bay, Labrador 26/27 Jan 92 18 to 05 AST

of an expanding and shrinking size of the convection pattern. When the pattern expands the antisunward flow of the dawn cell may be over Goose Bay explaining the observed westward drift.

4. Drift observations at Thule

In winter 1983/1984 AFGL's Airborne Ionospheric Observatory was deployed at Thule, Greenland and ionograms and drift observations were conducted with the Digisonde onboard the aircraft and four crossed-loop antennas on the runway nearby. Results of a number of 24-hour runs are shown in Figs. 4 and 5. Since Thule is close to the center of the polar cap we expect a continuous antisunward flow with its direction rotating 360° in 24 h. In magnetic coordinates the rotation is approximately linear in time as Thule rotates around the magnetic pole. In the examples shown, the general trend of the drift direction is approximately antisunward. On 9 December 1983 (Fig. 5) there are some large fluctuations in the drift direction during the evening hours and they coincide with the occurrence of sun-aligned arcs observed on 6300 Å with an all-sky imaging photometer [9]. Fig. 6 shows the results of four days of observation at the end of January 1984. Again, the drift direction closely follows the antisunward direction which is indicated in the figure. The observed velocities vary from about 300 to 800 m/s which is three times higher than the typical values at Goose Bay.

5. Conclusion

The exploratory observations made at a polar cap and an auroral station confirm that the ground-based Digisonde Doppler shift technique is capable of monitoring the high latitude convection pattern. The average plasma velocities vary from 100 to 300 m/s at the auroral station and from 300 to 800 m/s in the polar cap. Since the Danish Meteorological Institute is now operating a Digisonde at Qanaq (87° CGL) and the Air Force Geophysics Laboratory operates Digisondes at Goose Bay (65° CGL) and Argentia (58° CGL) it will be possible to more closely monitor the polar convection and to correlate the observations with other geophysical phenomena [10, 11], especially the geomagnetic activity, and with the variations in the IMF.

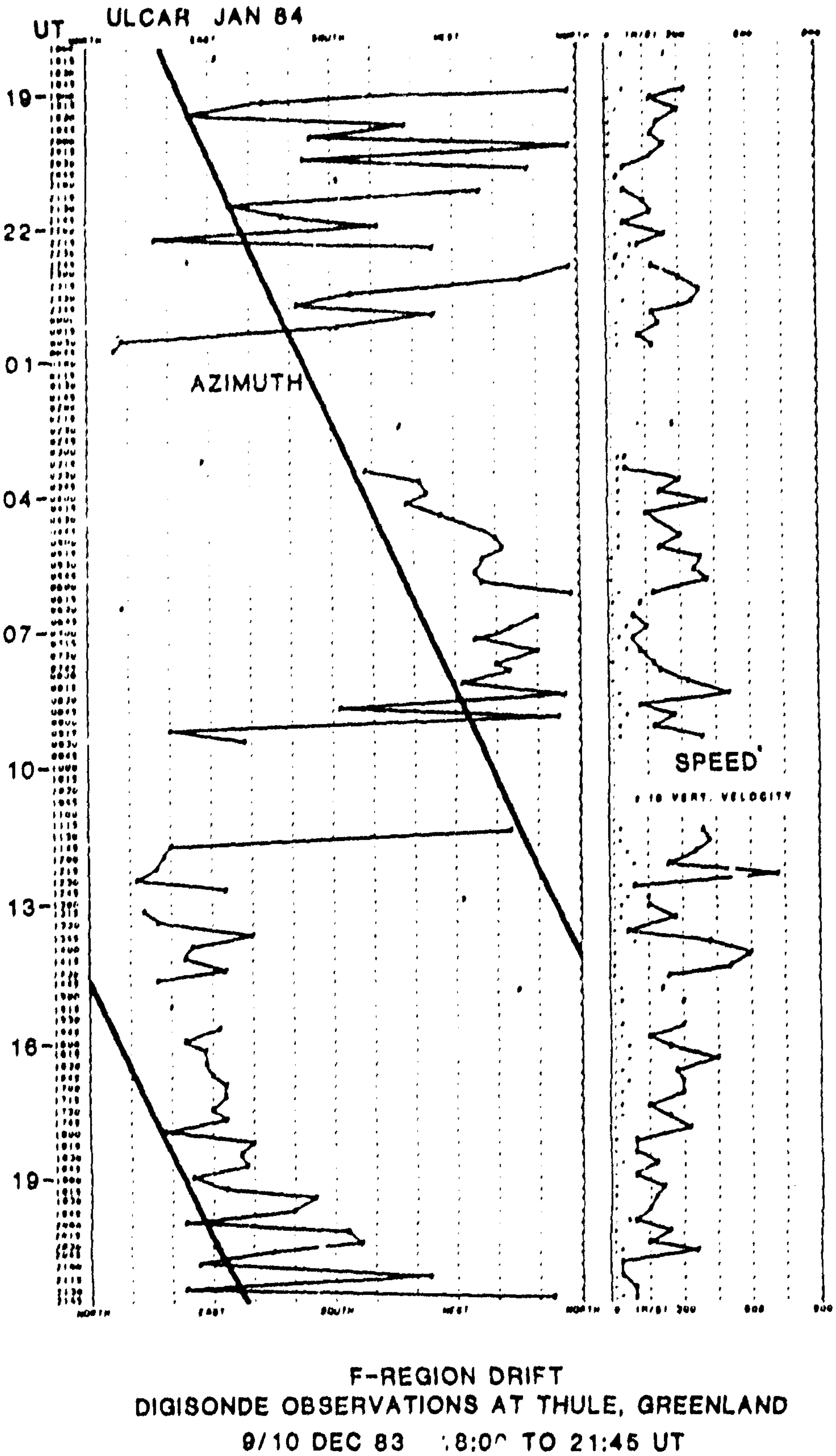

Fig. [illegible] F-region Drift at Thule, Greenland, 9/10 Dec 83, 18 to 22 UT. The drift direction vacillates around antisunward direction. The thin line connects the median values of the three-frequency observations (see caption of Fig. 3). Heavy line indicates the antisunward direction.

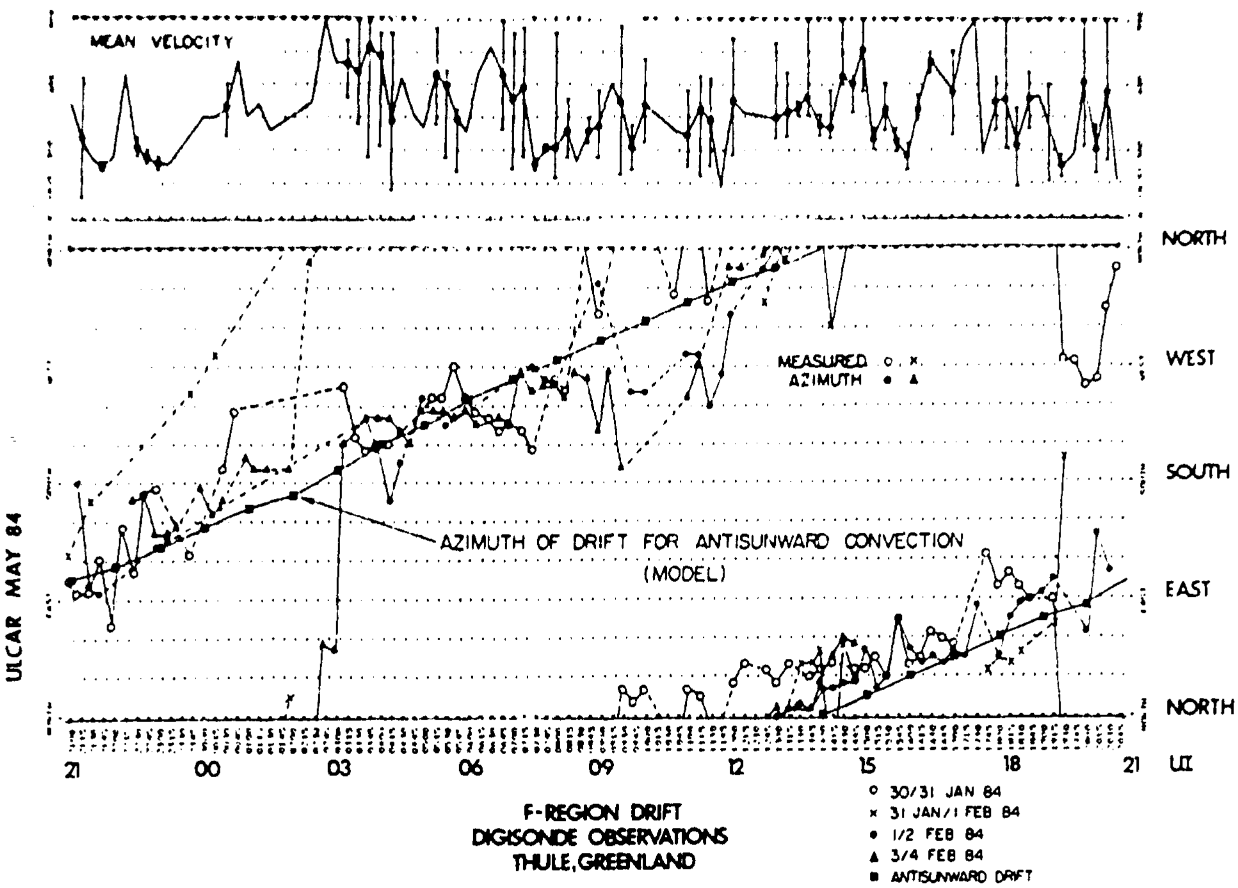

Fig. 6. F-Region Drift at Thule, 30 Jan to 4 Feb 84. Direction of the drift for four winter days is shown with reference to the antisunward direction. The velocity panel shows the mean velocity and the variations during the four days.

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The authors want to thank Mr. Claude G. Dozois of ULCAR for the processing of the drift data.

References

1. Cauffman, D. P. and Gurnett, D. A. Space Sci. Rev. 13, 369 (1972).
2. Reiff, P. H., Spiro, R. W. and Hill, T. W. J. Geophys. Res. 86, 7639 (1981).
3. Rezhenov, B. V., Planet. Space Phys. 29, 687 (1981).
4. Burke, W. J., Kelley, M. C., Sagalyn, R. C. Smiddey, M. and Lai, S. T., Geophys. Res. Lett. 6, 21 (1979).
5. Wygant, J. R., Torbert, R. B. and Mozer, F. S., J. Geophys. Res. 85, 5727 (1983).
6. Bibl, K. and Reinisch, B. W. Radio Sci. 13, 519 (1978).
7. Reinisch, B. W., Radio Sci. 21, 3, 331 (1986).
8. Bibl, K., Pfister, W., Reinisch, B. W. and Sales, G. S., COSPAR, Space Research XV, pp. 405–411 (1975).
9. Dozois, C. G., AFGL-TR-83-0202, ULRF-424 CAR, NTIS #ADA 140509 (1983).
10. Weber, E. J., Buchau, J., Moore, J. G., Sharber, J. R., Livingston, R. C., Winningham, J. D., and Reinisch, B. W., J. Geophys. Res. 89, 1683 (1984).
11. Buchau, J., Reinisch, B. W., Weber, E. J. and Moore, J. G., Radio Sci. 18, 995 (1983).

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VALUES OF h_mF2 DEDUCED FROM AUTOMATICALLY SCALED IONOGRAMS

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ABSTRACT

The values of hmF2 deduced by real-height analysis of automatically scaled vertical incidence Digisonde ionograms have been compared with those obtained using simple methods based on routinely scaled ionospheric characteristics. Comparisons have been made for ionograms recorded at five stations during low solar activity. The real-height analyses used Titheridge's program POLAN, while the simple methods used were those of Dudeney and Bilitza. Systematic discrepancies between the simple-model and POLAN values of hmF2 were found, with 15-20 km overestimates of hmF2 by the simple methods during the night. The majority of discrepancies lie between ±20 km. During the day, 80% of discrepancies lie between ±10 km. Significantly larger discrepancies can usually be attributed to special ionospheric conditions or ionograms, failure of the automatic scaling technique, or failure of one of the basic assumptions of the simple models.

SIMPLE MODELS OF THE IONOSPHERE

Simple models of the ionosphere have been used for many years in applications in which the errors in the resulting calculations are accepted because of the enormous decrease in computation times which such models permit. One of the most important practical applications is in the calculation of sky-wave field strengths and transmission losses at HF. See, for example, the Supplement to Report 252 /1/. For these calculations, the propagation modes involving reflection from the E and F layers are determined using an ionospheric model with parameters which depend on the routinely scaled values of foE, foF2, M(3000)F2 and h'F,F2.

The model currently recommended by CCIR consists of:

a parabolic E layer below its height of maximum electron density, hmE, with semi-thickness ymE. hmE and ymE are set to 110 km and 20 km, respectively.

a parabolic F2 layer with height of maximum density hmF2, and semi-thickness ymF2.

a linear increase of electron density between hmE and the point on the parabolic F2 layer where the plasma frequency is 1.7 foE.

The model value of hmF2 is given by the empirical equations /1, 2/:

$$hmF2 = 1490/[M(3000)F2 + dM] - 176$$

with $$dM = 0.18/(X - 1.4) + 0.096\ (R12 - 25)/150$$

and $$X = foF2/foE, \text{ or } 1.7,$$

whichever is the larger. R12 is the 12-month smoothed sunspot number.

The term dM is an empirical correction term which takes into account the effects of underlying ionization not allowed for in the original Shimazaki /3/ formulation. Model estimates of hmF2 are usually correct to within 20 to 30 km /1/. Dudeney /4/ has described an improved model which uses a cosine F2 layer shape and a more realistic E-F transition region, and has deduced that this model yields more accurate values of hmF2 than the Bradley-Dudeney model. Dudeney gives a revised formula for hmF2:

$$hmF2 - 1490\ F/(M + dM) - 176$$

where $$dM = 0.253/(X - 1.215) - 0.012$$

and $$F = M\,[(0.0196\,M^2 + 1)/(1.2967\,M^2 - 1)]^{0.5}.$$

The value of X is contrained to exceed 1.215.

In general, we have concentrated on the Dudeney /4/ model, but we have also studied the relative validity of the Bilitza et al. /5/ and Bradley and Dudeney /2/ models. We have analyzed about 1000 Digisonde 256 ionograms from five North American stations: Lowell, Massachusetts; Argentia, Newfoundland; Goose Bay, Labrador; Richfield, Utah; and Erie, Colorado. The ionograms were chosen on the basis of their ready availability, and do not necessarily represent a statistically perfect sample.

The required values of foE, foF2 and M(3000)F2 were provided by the autoscaling software ARTIST which is part of the Digisonde /6, 7/. The virtual height traces scaled from the ionograms using ARTIST were passed to the true-height analysis program POLAN /8/, to provide reliable estimates of hmF2.

DISCREPANCIES BETWEEN POLAN AND SIMPLE MODEL VALUES OF hmF2

We have analyzed the differences between the POLAN and Dudeney values of hmF2 according to the value of X (= foF2/foE) and to the value of the correction term dM. The differences have been distributed among bins 5 km wide, with extreme negative/positive values being placed in the <-30/>30 km bin. Negative discrepancies indicate that the POLAN value was less than the Dudeney value.

Tables 1 and 2 show the distributions of the discrepancies for dM values of 0.0 to 0.1, and 0.11 to 0.5, respectively. Broadly speaking, the low values of dM (Table 1) correspond to nighttime ionograms, and the high values to daytime ionograms. It can be seen that the Dudeney result is systematically higher than the POLAN result at night, by about 15 ± 15 km. During the day, there is no significant systematic discrepancy between the two sets of results, and 81% of the discrepancies lie within ±10 km. [Note that the extreme values are ignored when calculating the percentages.] There were 69 Argentia and Erie ionograms for which dM exceeded 0.5. When the discrepancies greater than 30 km are ignored, the average discrepancy for the remaining 48 cases was 15 - 20 km, the Dudeney values being the larger.

ΔhmF2 (km)	LOW	ARG	GB	UTAH	ERIE	TOTAL	%
< -30	2	29	3	1	0	35	-
-30 -25	3	18	7	5	0	33	11
-25 -20	4	24	4	13	0	45	15
-20 -15	11	31	9	19	2	72	23
-15 -10	9	18	1	16	2	46	15
-10 - 5	8	12	2	20	4	46	15
- 5 0	5	4	2	9	1	21	7
0 5	7	2	0	4	0	13	4
5 10	2	2	1	2	0	7	2
10 15	2	1	0	8	0	11	4
15 20	4	0	0	3	0	7	2
20 25	2	1	0	1	0	4	1
25 30	0	2	0	2	0	4	1
> 30	4	6	3	8	0	21	-
N	63	150	32	111	9	365	309

Table 1. Distribution of differences between the POLAN and Dudeney values of hmF2, for 0.0 ≤ dM < 0.10 (Night). A positive value of ΔhmF2 indicates that the POLAN value was greater than the Dudeney value.

ΔhmF2 (km)	LOW	ARG	GB	UTAH	ERIE	TOTAL	%
< -30	0	1	0	0	5	6	-
-30 -25	0	0	0	0	1	1	0
-25 -20	0	0	0	0	1	1	0
-20 -15	0	1	1	0	0	2	0
-15 -10	2	3	2	9	5	21	4
-10 - 5	3	11	4	50	10	78	16
- 5 0	6	29	8	61	22	126	27
0 5	6	49	4	24	25	108	23
5 10	4	34	9	7	19	73	15
10 15	3	11	4	2	14	34	7
15 20	2	8	1	3	0	14	3
20 25	3	2	2	1	1	9	2
25 30	0	5	0	2	0	7	1
> 30	6	3	5	6	1	21	-
N	35	157	40	165	104	501	474

Table 2. Distribution of differences between the POLAN and Dudeney values of hmF2, for $0.11 \le dM \le 0.50$ (Day).

Figure 1 shows the distributions of the discrepancies for four ranges of X. The discrepancies change from being systematically positive for low X values, to being systematically negative for large X values.

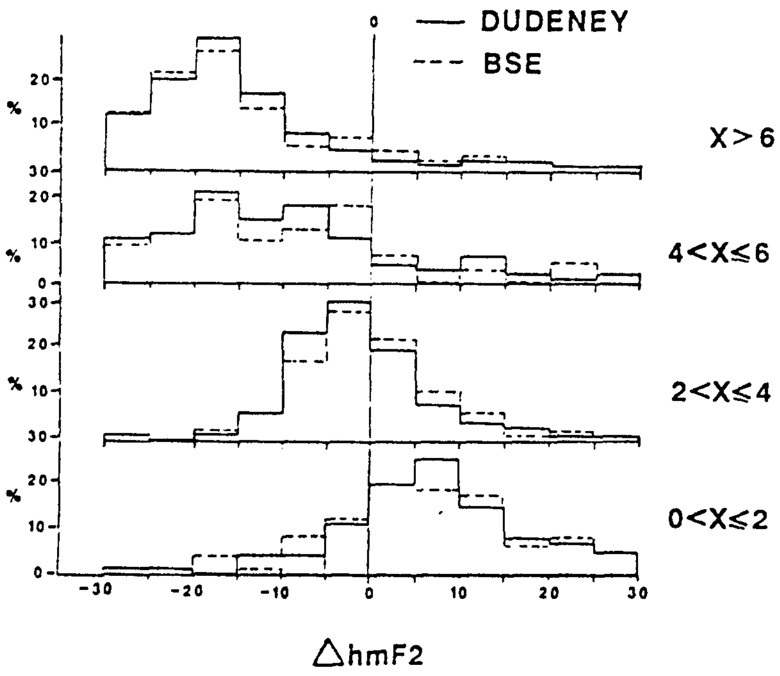

Figure 1. Distribution of the discrepancies in km between the POLAN and model values of the height of the F2-layer peak, hmF2. The ordinates are percentages, and values lying outside the 30 km limits have been ignored. The parameter X is defined by X = foF2/foE.

The systematically high values of hmF2 given by the simple formulas at night can be traced to the models' neglect of underlying ionization. The effect of this underlying ionization was originally considered to be insignificant a decade or so ago, which it indeed was in comparison with the effect of the E and F1 layers during the day. However, the daytime models have been improved to the point where the nighttime errors are now the largest obtained.

REFERENCES

1. CCIR, "Second CCIR computer-based interim method for estimating sky-wave field strength and transmission loss at frequencies between 2 and 30 MHz," Supplement to Report 252, International Radio Consultative Committee, International Telecommunication Union, Geneva, Switzerland (1980).

2. P. A. Bradley and J. R. Dudeney, "A simple model of the vertical distribution of electron concentration in the ionosphere," J. Atmos. Terr. Phys., 35, pp. 2131-2146 (1973).

3. T. Shimazaki, "World-wide daily variations in the height of the maximum electron density in the ionospheric F2 layer," J. Radio Res. Labs., Japan, 2(7), pp. 86-97 (1955).

4. J. R. Dudeney, "The accuracy of simple methods for determining the height of the maximum electron concentration of the F2 layer from scaled ionospheric characteristics," J. Atmos. Terr. Phys., 45, pp. 629-640 (1983).

5. D. Bilitza, N. M. Sheik and R. Eyfrig, "A global model for the height of the F2 peak using M3000 values from the CCIR numerical maps," Telecomm. J., 46, pp. 549-553 (1979).

6. B. W. Reinisch and Huang Xueqin, "Automatic calculation of electron density profiles from digital ionograms. 3. Processing of bottomside ionograms," Radio Science, 18(3), pp. 477-492 (1983).

7. B. W. Reinisch, R. R. Gamache and J. S. Tang, "Automatic electron density profiles from digital ionograms," AGARD, Conference Proceedings No. 345, "Propagation factors affecting remote sensing by radio waves" (1984).

8. J. E. Titheridge, "Ionogram analysis with the generalized program POLAN," World Data Center A for Solar-Terrestrial Physics Report UAG-93, Boulder, CO (1985).

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